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for: METHOD AND APPARATUS FOR DETERMINING CHANNEL CONDITIONS IN A
COMMUNICATION SYSTEM

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Title page stamped with Certificate of Express Mail
 12-page Specification and Claims
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November 28, 2000
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Leanora L. Petrowski
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**APPLICATION FOR UNITED STATES
LETTERS PATENT**

**METHOD AND APPARATUS FOR DETERMINING CHANNEL CONDITIONS
IN A COMMUNICATION SYSTEM**

By:

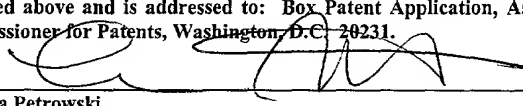
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Leanora Petrowski

METHOD AND APPARATUS FOR DETERMINING CHANNEL CONDITIONS IN A COMMUNICATION SYSTEM

TECHNICAL FIELD

The invention in one embodiment relates generally to communication networks and,
5 more particularly, to communications over wireless and cellular data networks.

BACKGROUND

With the rapid growth of wireless communications, the industry is developing and
implementing a variety of transmission protocols in order to provide faster, more robust and
more efficient communications. System performance can be improved by choosing the
10 appropriate symbol rate, modulation and coding scheme and transmit power under the
prevailing channel conditions. In order to select the best protocol, the transmitting station
must have reliable current knowledge of the prevailing channel conditions at the receiver.
Determining the prevailing channel conditions has proven to be computationally complex and
susceptible to error. Accordingly, there is a need for a reliable, simple, efficient way to obtain
15 current knowledge of the prevailing channel conditions in a communication link

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of one example of a system;

FIG. 2 is a block diagram of exemplary components for computing symbol error
probability in the system of FIG. 1;

20 FIG. 3 is a block diagram of exemplary components for computing symbol error
probability in the system of FIG. 1;

FIG. 4 is a block diagram of an exemplary employment of symbol error probability for selection of modulation and coding schemes, for rate adaptation and power control in the system of Fig. 1;

FIG. 5 is a flow diagram illustrating determination of channel conditions in the system of Fig. 1;

FIG. 6 is a graph showing curves of the mean bit error probability (vertical scale) versus carrier to interference ratio (horizontal scale) computed for different environments and mobile speeds for the system of Fig. 1.

DETAILED DESCRIPTION

Turning to Fig. 1, the system 100 in one example includes a plurality of components such as computer software and/or hardware components. A number of such components can be combined or divided in different configurations. For example, the invention may be implemented employing at least one computer-readable signal-bearing medium. One example of a computer-readable signal-bearing medium comprises an instance of recordable data storage medium 101 such as one or more of a magnetic, optical, biological, and atomic data storage medium. In another example, a computer-readable signal-bearing medium comprises a modulated carrier signal transmitted over a network comprising or coupled with systems over a local area network ("LAN"), the Internet, and a wireless network. An exemplary component of a system employs and/or comprises a series of computer instructions written in or implemented with any of a number of programming languages, as will be appreciated by those skilled in the art.

Referring to FIG 1, in one example, system 100 includes a transmitter 110 which receives data 102 to be transmitted. Data 102 in one example, can be represented as an information bit sequence $\{a_k\}$. Encoder 112 in one example comprises a block encoder or a convolutional encoder. For example, encoder 112 encodes the information bit sequence $\{a_k\}$ to output a coded sequence $\{c_k\}$. An interleaver 114 interleaves the coded sequence $\{c_k\}$. Coded sequence $\{c_k\}$ is then mapped to a symbol sequence by a symbol mapper 116. At symbol mapper 116, each symbol is chosen from an M-ary signal constellation. In other words, the Coded sequence $\{c_k\}$ is transformed into a finite set of M-ary symbols where M corresponds to the number of symbols.

The code rate and symbol mapping are chosen based on channel quality feedback from a receiver in the manner described below. A transmit filter 118 performs pulseshaping to improve waveform characteristics for transmission of the signal over the air or other transmission medium. The resulting signal is transmitted over a fading dispersive channel 120. The signal is also degraded by additive white gaussian noise (AWGN) 121 input to the channel at adder 122.

Receiver 123 receives the transmitted signal the over fading dispersive channel 120. Front end analog receive filter 124 processes the incoming signal from fading dispersive channel 120. Receive filter 124 is matched to operate with transmit filter 118. Sampler 126 periodically samples the output of receive filter 124.

Multipath or time dispersion characteristics can result in inter symbol interference (ISI) that significantly degrades performance. Decision device 128 is typically employed in order to mitigate the effect of ISI. It is possible to use a decision device that provides either *hard* (e.g., binary) outputs corresponding to the received raw symbol sequence or to employ a

decision device that provides *soft* outputs in the form of probabilities or log likelihood ratios. System 100 in one example uses a decision device 128 at the receiver to provide soft outputs.

Soft outputs may be obtained from appropriate decoders or equalizers. For example, minimum Euclidean distance decoders (*e.g.*, Viterbi decoders) can use soft outputs in order to carry out soft decision decoding (*See* J. Hagenauer and P. Hoeher, "A Viterbi Algorithm with Soft Decision Outputs and its Applications," *Proceedings, IEEE Globecom*, 1989 incorporated herein by reference). Examples of equalization techniques that can generate log likelihood ratios include the Bahl-Cocke-Jelinek-Raviv (BCJR) *Maximum a Posteriori* (MAP) algorithm, L. R. Bahl, J. Cocke, F. Jelinek and J. Raviv, "Optimal Decoding of Linear Codes for Minimizing Symbol Error Rate," *IEEE Trans. On Information Theory*, Vol. IT-20, pp. 284-287, March 1974, and the *Soft Output Viterbi Algorithm* (SOVA), J. Hagenauer and P. Hoeher, "A Viterbi Algorithm with Soft Decision Outputs and its Applications," *Proceedings, IEEE Globecom*, 1989, incorporated herein by reference for background purposes.

The soft outputs used in system 100 are obtained from decision device 128 which can be either an equalizer or a demodulator or both. In general, soft outputs represent the likelihood or probability of each received raw symbol being the value that it is assumed to be for decoding operations. For example, in the case of a binary transmission, ($M=2$), the soft outputs represent the probability of each raw symbol being a '1' (p_1) or a '0' (p_0). In another aspect of system 100, decision device 128 generates a *log likelihood ratio* (*i.e.*, $\log(p_1)-\log(p_0)$) value for each raw symbol.

Regardless of whether log likelihood ratios or probabilities are obtained from decision device 128, the values corresponding to each symbol need to be averaged to obtain an error rate estimate that is representative of channel conditions. Two methods for computing the

mean Symbol Error Probability (SEP) are shown for purposes of illustration. A first method is shown in Figure 2. For each raw symbol, c_k , decision device 228 generates the *a posteriori* probability mass function, $p_i(c_k)$ and $p_o(c_k)$, from the set of observations at the output of the communication channel where

$$\begin{aligned} p_i(c_k) &= \text{Probability}\{c_k = 1 \mid \text{observations at decision device input}\} \text{ and} \\ p_o(c_k) &= (1 - p_i(c_k)). \end{aligned}$$

From p_o and p_i , processor 230 computes the SEP for c_k as

$$\text{SEP}(c_k) = \min[p_o(c_k), p_i(c_k)].$$

Processor 232 then computes the mean SEP or mean symbol error rate estimate as a moving average of symbol error probabilities. Of course, calculating a moving average of symbol error probabilities can be done in a variety of different ways as would be familiar to one of ordinary skill in the art. The mean SEP output from processor 232 is provided as feedback to transmitter 110. Transmitter 110 compares the mean SEP to pre-determined thresholds in order to determine the coding and modulation scheme, signal power, or other communication protocol to use for subsequent transmissions. Alternatively, selection of appropriate coding and modulation schemes, signal power, or other communication protocol can be performed at the receiver 123. In such case, receiver 123 signals transmitter 110 to use the new protocol.

In another example, shown in Figure 3, decision device 328 generates a log likelihood ratio, $r(c_k) = \log(p_i) - \log(p_o)$. Assuming logarithms to the base e , p_i and p_o are computed by using $p_o = (1 - p_i)$, as follows:

$$p_i(c_k) = 1 / (1 + \exp(r(c_k)))$$

$$p_o(c_k) = 1/(1+\exp(-r(c_k)))$$

From p_o and p_i , processor 330 computes the symbol error probability (SEP) for c_k as

$$\text{SEP}(c_k) = \min[p_o(c_k), p_i(c_k)].$$

Processor 332 then computes the mean SEP as a moving average of the SEPs for each raw symbol. The mean SEP output from processor 332 is then provided as feedback to transmitter 110. As noted with regard to the example of Figure 2, transmitter 110 compares the mean SEP to pre-determined thresholds in order to determine the coding and modulation scheme or other communication protocol to use for subsequent transmissions. FIG. 4 depicts a block diagram of an exemplary communication system employing mean SEP for MCS, rate adaptation and power control.

A flowchart generally illustrating the operation of system 100 is shown in Fig 5. In the method 500, M-ary symbols are received over a communications channel in step 502. A decision device at a communication receiver determines soft decision metrics for each of the M-ary symbols received in step 504. These soft decision metrics may be calculated according to the *a posteriori* probability mass function, $\{p_o, p_1, p_2, \dots, p_M\}$, as explained above. In Step 506, SEPs are determined for each of the M-ary symbols from the probabilities determined in step 504 using

$$\text{SEP} = 1 - \max(p_o, p_1, p_2, \dots, p_M).$$

Alternatively, the decision device determines the *a posteriori* probability mass function, $\{p_o, p_1\}$ for each of the $\log_2 M$ bits represented by an M-ary symbol received in step 504. In Step 506, the Bit Error Probability (BEP) is computed for each of these bits from the probabilities determined in step 504 using

$$\text{BEP} = 1 - \max(p_0, p_I).$$

In order to obtain a good overall error rate estimate, a moving average of the SEPs or BEPs is calculated in step 508. The moving average is fed back to the transmitter in step 510. The transmitter compares the moving average to thresholds in step 512 and determines in step 514 whether any predetermined thresholds for communication protocol changes have been met or exceeded. If a threshold has been met or exceeded, the transmitter selects a new communication protocol in step 516 and informs the receiver of the new protocol in step 518. Alternatively, the receiver can employ the symbol error probability to select a communication protocol and signal the transmitter to implement the new communication protocol. The new protocol is implemented and the process of determining the reliability of the communication channel repeats under the new protocol.

As shown in Figure 4, in addition to MCS selection, virtually any communication protocol that is changed depending on a change in channel conditions can be modified based on SEP or BEP estimates made according to system 100. In general, system 100 will prove useful in information transmission systems where SEP or BEP estimates are used to adjust modulation and coding schemes or other communication protocols in response to changing channel conditions and where soft outputs can be derived from a decision device at the receiver. For example, in addition to selecting the best modulation and coding scheme, system 100 can be used in connection with the adjustment of transmitter power levels and in making handover decisions. System 100 is applicable to both uplink and downlink communications.

Simulations were carried out in order to study the behavior of the mean BEP determined according to system 100. The simulations assume 8-PSK ($M=8$, i.e., 8 phase shift

keying) modulation, GSM symbol rate, training sequence and burst structure. Both Typical Urban (TU) and Hilly Terrain (HT) channel models are considered and different mobile speeds are assumed.

Figure 6 shows the mean BEP as a function of carrier to interference ratio (C/I) for different environments and mobile speeds. The results indicate that for a fixed delay spread environment (*e.g.*, HT), the mean BEP is invariant across mobile speeds. The mean BEP also shows more degradation as the amount of dispersion increases. This validates the BEP measure derived according to system 100 since it includes the effect of the received signal and interference power as well as other receiver impairments. This behavior is also consistent with the Bit Error Rate performance that would be observed in the uncoded case.

The flow diagrams depicted herein are just exemplary. There may be many variations to these diagrams or the steps or operations described therein without departing from the spirit of the invention. For instance, the steps may be performed in a differing order, or steps may be added, deleted, or modified.

Although exemplary embodiments of the invention have been depicted and described in detail herein, it will be apparent to those skilled in the relevant art that various modifications, additions, substitutions, and the like can be made without departing from the spirit of the invention and these are therefore considered to be within the scope of the invention as defined in the following claims.

CLAIMS

We claim:

1. A method, comprising the steps of:

determining a soft decision metric at a receiver for a plurality of symbols
transmitted over a communication channel; and

employing the soft decision metric to determine symbol or bit error
probability.

2. The method of claim 1, wherein the step of determining the soft decision metric for a
plurality of symbols comprises the steps of:

observing the output of the communication channel; and

determining a derived probability for each one of the plurality of transmitted
symbols through employment of a set of observations at the output of the
communication channel.

3. The method of claim 1, further comprising the step of deriving an error rate estimate
as a moving average of the symbol or bit error probability.

4. The method of claim 3, further comprising the step of employing the error rate
estimate in providing feedback to a transmitter.

5. The method of claim 1, wherein the step of determining the soft decision metric for
the plurality of symbols comprises the step of deriving the soft decision metric from an
output of at least one of an equalizer and a demodulator.

6. The method of claim 5, wherein the output of the equalizer or demodulator comprises
a log likelihood ratio.

7. The method of claim 1 wherein the transmitted symbols comprise binary values.
8. The method of claim 1, further comprising the step of employing the symbol or bit error probability to select a communication protocol.
9. The method of claim 8, wherein the step of employing the symbol or bit error probability to select a communication protocol is performed at the transmitter.
10. The method of claim 8, wherein the step of employing the symbol or bit error probability to select a communication protocol is performed at the receiver.
11. The method of claim 8, wherein the step of employing the symbol or bit error probability to select the communication protocol comprises the step of selecting at least one of a modulation scheme, a coding scheme, symbol rate, and power level.
12. The method of claim 8, wherein the step of employing the symbol or bit error probability to select a communication protocol comprises the step of comparing the symbol error probability to one or more predetermined thresholds.
13. A system comprising:
 - 15 a transmitter that transmits a plurality of symbols over a communication channel;
 - a receiver that receives a plurality of symbols over the communication channel;
 - a decision device that provides a plurality of soft decision metrics for a plurality of symbols received over the communication channel;
 - a processor that obtains an error rate estimate through employment of symbol or bit error probability values computed from the soft decision metrics.
14. The system of claim 13, further comprising a feedback link that communicates an error rate estimate from the receiver to the transmitter.

15. The system of claim 14, further comprising a selector circuit that changes a communication protocol in response to the error rate estimate.

16. The system of claim 13, further comprising a selector that changes one or more of a modulation and coding scheme in response to the error rate estimate.

5 17. The system of claim 13 wherein the decision device comprises one or more of a demodulator and an equalizer.

18. The system of claim 13 wherein the decision device performs demodulation through employment of a Viterbi decoder algorithm or a variant thereof.

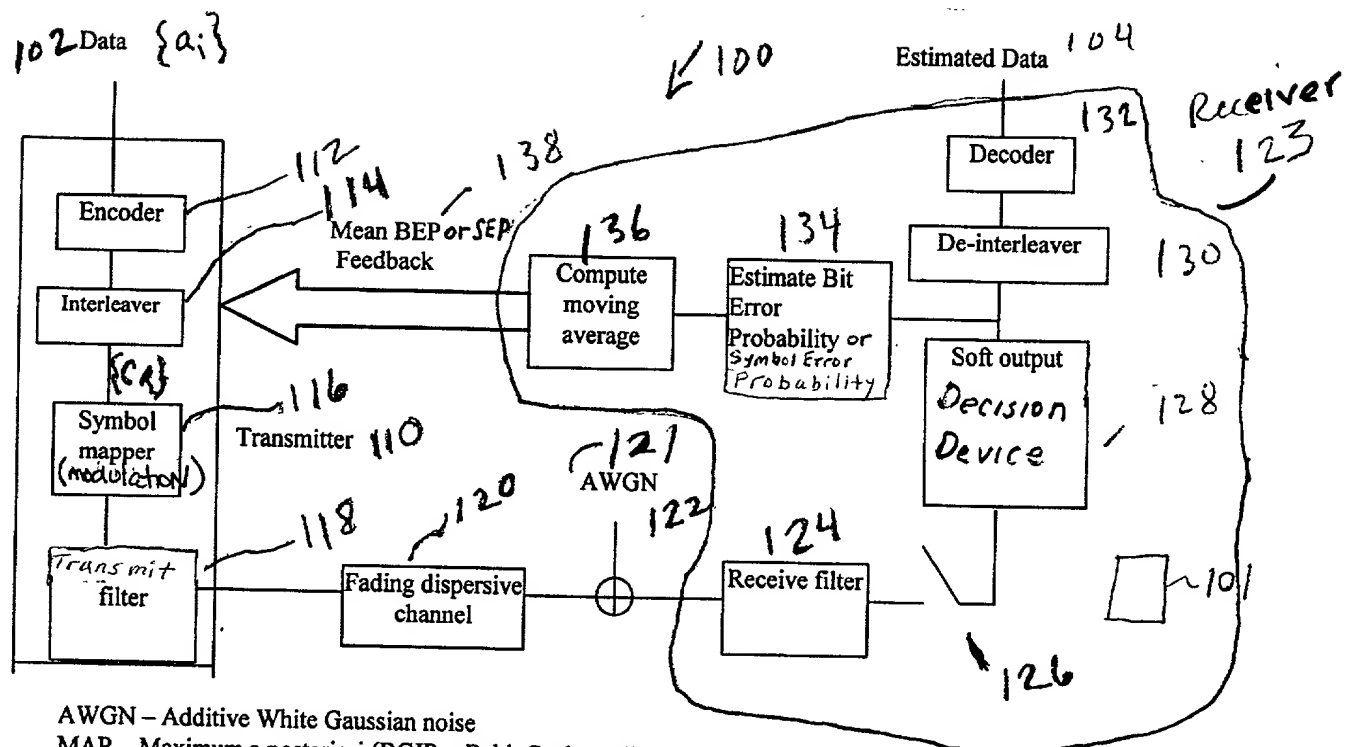
10 19. The system of claim 13 wherein the decision device performs equalization through employment of one or more of a Bahl-Cocke-Jelinek-Raviv algorithm, a soft output Viterbi algorithm, or variants thereof.

20. An article, comprising:

a computer-readable signal-bearing medium;

15 means in the medium for determining a soft decision metric at a receiver for a plurality of symbols transmitted over a communication channel; and

means in the medium for employing the soft decision metric to determine symbol or bit error probability.



AWGN – Additive White Gaussian noise
 MAP - Maximum a posteriori (BCJR – Bahl, Cocke, Jelinek and Raviv [3])
 SOVA – Soft Output Viterbi Algorithm

Figure 1: Block Diagram of System

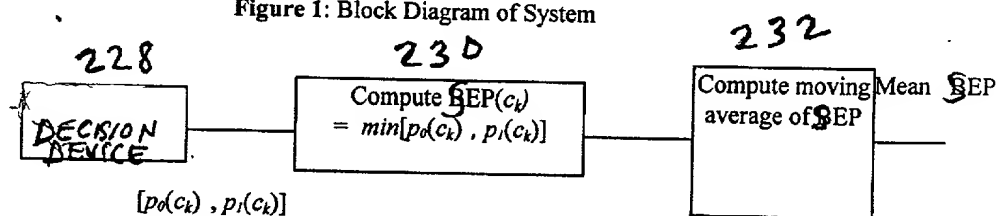


Figure 2: Computation of Mean SEP (Method 1)

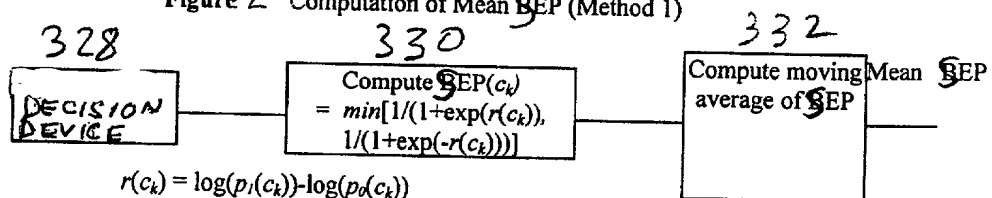
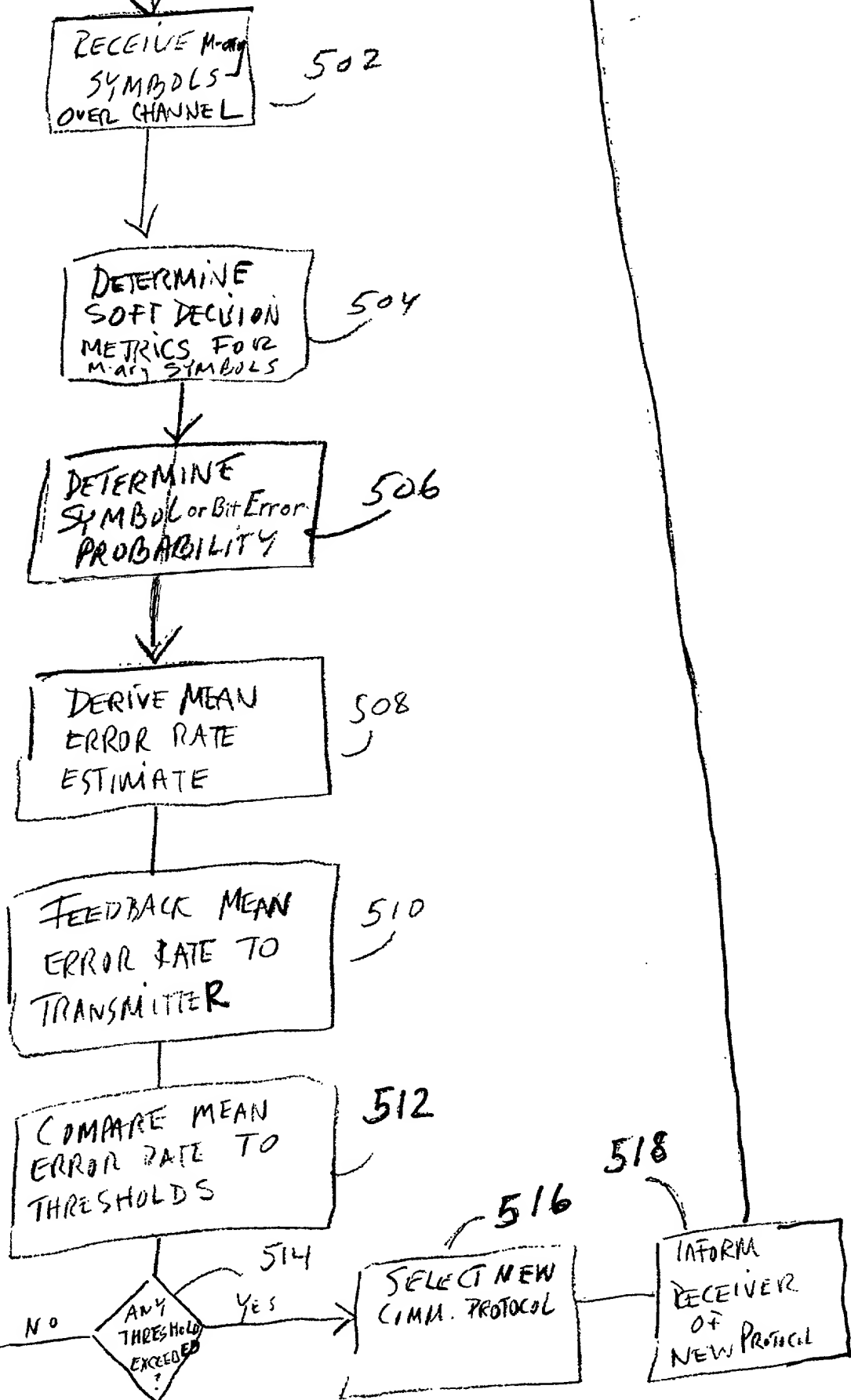


Figure 3: Computation of Mean SEP (Method 2)

FIG 5



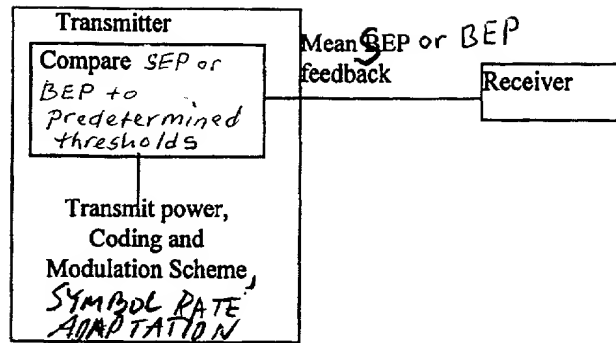


Figure 4: Use of Mean BEP or SEP for Rate Adaptation and Power Control

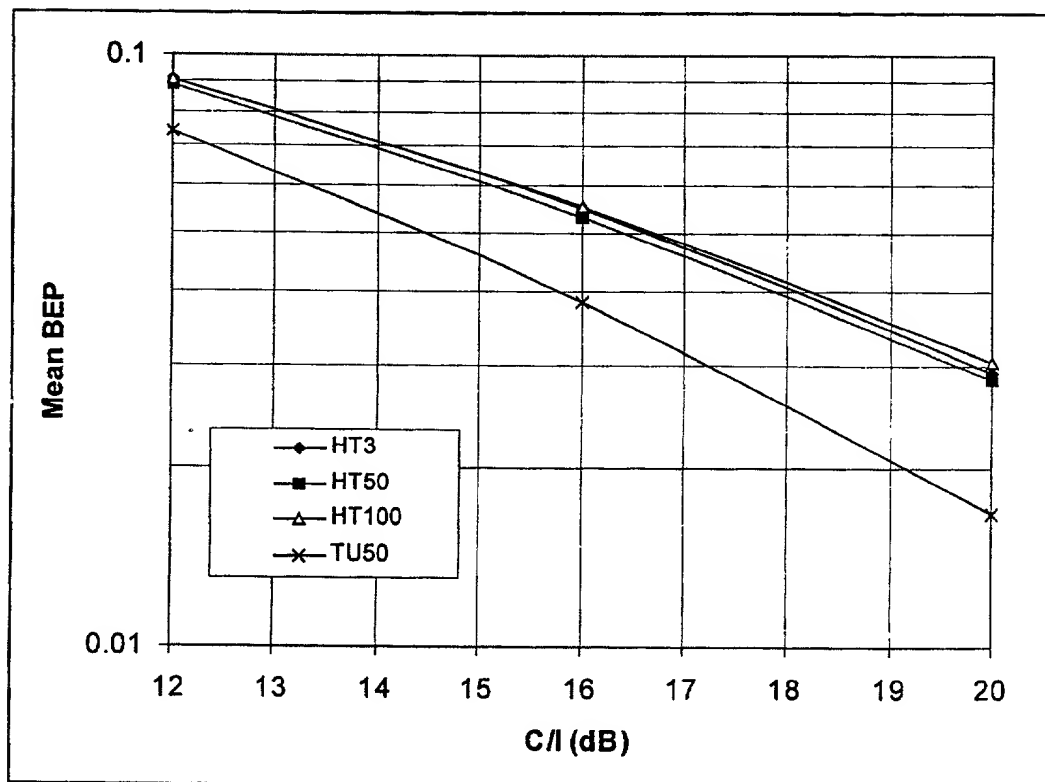


Figure 6 Mean Bit Error Probability estimate for different environments and mobile speeds; HT3 represents the channel model for a mobile speed of 3 km/h in a Hilly Terrain environment.

IN THE UNITED STATES
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Declaration and Power of Attorney

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe the below named inventors are the original, first and sole inventors of the subject matter which is claimed and for which a patent is sought on the invention **METHOD AND APPARATUS FOR DETERMINING CHANNEL CONDITIONS IN A COMMUNICATION SYSTEM** the specification of which *is attached hereto*.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by an amendment, if any, specifically referred to in this oath or declaration.

I acknowledge the duty to disclose all information known to me which is material to patentability as defined in Title 37, Code of Federal Regulations, 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

None

I hereby claim the benefit under Title 35, United States Code, 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, 112, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

None

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

033311-1-10

I hereby appoint the following attorney(s) with full power of substitution and revocation, to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent and Trademark Office connected therewith:

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